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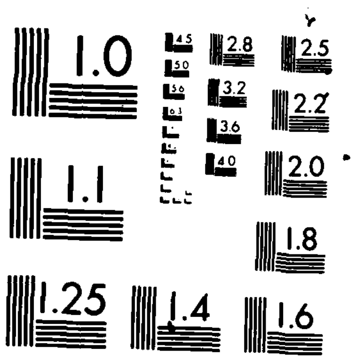

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A STUDY ON EEATURES OF FLOW FIELD AND ATMOSPHERIC DISPERSION PARAMETERS IN MOUNTAINOUS AREA BY BALANCED BALLOONS

by

Jiang Weimei, Zhou Chaofu, et al.

FOREIGN TECHNOLOGY DIVISION

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A STUDY ON FEATURES OF FLOW FIELD AND ATMOSPHERIC DISPERSION PARAMETERS IN MOUNTAINOUS AREA BY BALANCED BALLOONS

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Study results of flow field feature

Results of this study on features of flow field and atmospheric diffusion parameters are described, ~~in~~ the paper. The analysis shows that there are some obvious and significant flow patterns in mountainous area, such as valley breeze, channel wind, fumigation and thermal effect of industrial sources etc. The parameters in three dimensions have been obtained by probing on site.

In this paper, some of the problems associated with the calculation of parameters by the method of sliding average using limited number of data are discussed. By using mathematical simulation, the relationship between sampling time and time interval of the sliding average has been analyzed.

A STUDY ON FEATURES OF FLOW FIELD AND ATMOSPHERIC DISPERSION PARAMETERS IN MOUNTAINOUS AREA BY BALANCED BALLOONS

Jiang Weimei, Zhou Chaofu, Li Zongkai and Pan Yunxian.
(Department of Meteorology, Nanjing University)

Zhu Zengwang and Tang Shibao.
(Environmental Monitoring Station, Dukou City)

This paper introduces the results of a study on features of planetary boundary layer flow field and rules of atmospheric dispersion at an industrial base in a mountainous area by using the balanced balloon observation method. The analysis shows that there are obvious flow field features such as valley breeze, channel wind, fumigation and effects of local industrial heat sources. Three-dimensional atmospheric dispersion parameters have been obtained by on-site probing. In this paper, problems associated with the calculation of atmospheric dispersion parameters by the method of sliding average using limited number of data are also discussed. By using the method of mathematical simulation, the relationship between the time interval and sampling time of the sliding average has been analyzed.

I. Preface

The balanced balloon can be used as an indicating particle to show the movement of air particles. From the trajectory of its movement, the conditions of air flow field can be understood and the atmospheric dispersion capability estimated. From December 1981 to

January 1982, we conducted observation experiments of balanced balloons on both banks of the Jingsha River at Dukou area in Sichuan Province and obtained good results.

A regular No. 20 weather balloon field with hydrogen and carbon dioxide at a ratio of 1.7:1.0 was used as the balanced balloon. The balloon was carried by a captive balloon to an altitude of 250 meters and released through a special releasing device. The bivane anemometer was used to trace its movement and readings were taken at 15 second intervals. In order to assure a balanced mass of the balanced balloon, various specialized performance tests were conducted before the experiment. The operation conditions and observation procedures were strictly controlled during the tests, and the balance performance was reliable[1].

II. Track Analysis And Features Of Mountainous Flow Field

The projection method and vector method were used successively to compute the trajectories of the balanced balloons[2]. There was essentially no difference in the balloon location determined by the two methods; the only difference was in computation. Actual computations have shown that the vector method results in higher accuracy and that it can directly use short lines to indicate index errors. Its requirements for setting up a baseline are not stringent. The computation results can be markedly improved under conditions when the balloon crosses the baseline or its trajectories become more complex. The vector method is better suited for computation using a computer, thus it has supeiority. Certainly its computations are

more involved and not as convenient as those of the projection method.

After obtaining the location of the balloon, the coordinate axes were set according to geographical directions with the releasing point as the origin. Then the horizontal and vertical movement trajectories were plotted on the grid paper and the movement distance of the balloon during a certain period could be directly determined from the plot. Using the above method and a selection process, 135 effective trajectories were obtained (see Fig. 1) for the use of the analysis and computation of the atmospheric dispersion parameter. Several typical flow field features in a mountainous area were discovered after the analysis:

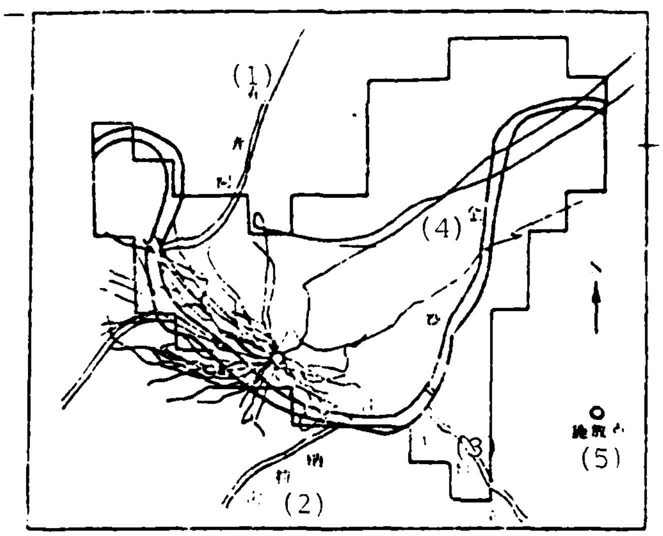

Fig. 1. Horizontal trajectories of the balloons during the experiment
Key: (1) Nong Nong ditch; (2) Nala ditch; (3) Renke Ditch;(4) Jingsha River; (5) releasing point.

1. Features Of Valley Breeze

In Fig. 1, if an observation point is used as the origin and let the x axis point to the north and the y axis to the east, then the number of balloon trajectories in quadrants I, II, III and IV of the normal coordinant system are 4, 49, 36 and 46, respectively. The analysis indicates that the releasing time of balloons in quadrants II and III IV were mostly between afternoon and dusk, and the atmospheric structures were mostly unstable while a few were neutral after sunset. The releasing time of balloons in quadrants IV were mostly between morning and noon, and the atmospheric structures were mostly in the interim period between stable and neutral. It can be observed from the daily change in local wind patterns that the westwardly flight trajectories in quadrants II and III coincide with valley breeze and those of the southeastwardly in quadrant IV coincide with the mountain breeze. Around 11 a.m. local time is exactly the time when the night-time mountain breeze starts changing to valley breeze and 11 p.m. is the time when the daytime valley breeze starts changing to mountain breeze[4].

2. Fumigation Process

Since the fumigation process often occurs at the same time as the mountain valley breeze changing time (around 11 a.m.) at the Dukou area, high ground level air pollutant concentration results. This fumigation process can be clearly seen on the flight trajectories of the balanced balloons. The local terrain calls for the flight trajectories of this process to be all in quadrant IV and between 8, 9 a.m. to around 11 a.m.

There were 10 such trajectories during the experiment. Figure 2 shows two typical groups of examples. The existence and development of a temperature inversion layer could be seen from the low altitude temperature probing conducted simultaneously. The trajectory analysis shows: (1) the occurrence of fumigation process will certainly bring air pollutants at high stratus to the ground; (2) the balloon changes flight direction at a certain altitude in the low stratus, and the altitude for direction change rises as time goes on; (3) as time goes on the touchdown point of the balloon moves closer and closer to the releasing point.

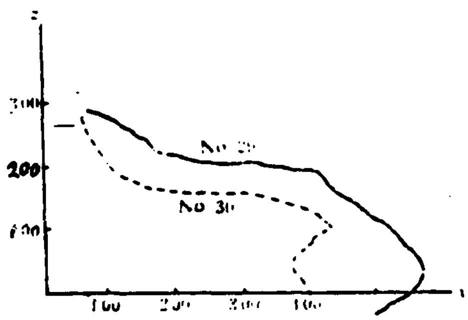

Fig. 2. Trajectories of balloon under a typical fumigation process
No. 29: WNW, $\bar{u}$=0.45 m/s, 1981.12.28, 10:55'15"
No. 30: WNW, $\bar{u}$=0.48 m/s, 1981.12.28, 11:27'15"

3. Effects Of Local Industrial Heat Sources

The two groups of flight trajectories in Fig. 3 show that, after releasing, the balloon started to descend due to the effects of downward air flow. But when it flew over the high temperature plume of a large industrial source, it was being pushed upward and within 1 to 2 minutes, it rose 155 meters and 70 meters, respectively. The atmospheric structure was stable at this time. Thus, we used the plume rise formula under corresponding conditions to calculate plume rises,

and the values were 123 meters and 78 meters, respectively. These were very consistent with the heights of balloon rise at that location. This phenomenon indicates, at the very least, that the effects of local large industrial heat sources cannot be ignored.

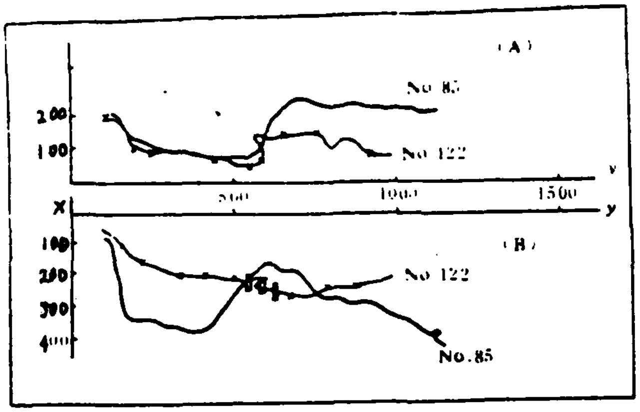

Fig. 3. Effects of industrial heat sources

4. Effects Of Channel Wind

It can be seen from the two examples shown in Fig. 4 that after the balloons crossed the Jingsha River from east to west, their flight directions were consistent with the channel direction except that the latter half of the flight of No. 77 deviated slightly. This was because the balloon kept rising as it flew over the river. When it reached above 450 meters it started to deviate from the channel direction. This shows that the effects of the channel can reach an altitude between 400 and 500 meters. The effects of channel downward air flow were slightly visible. But since the atmospheric conditions during the flight of the two groups of trajectory were quite unstable, the effects of air flow were greater and part of the effects of downward air flow were covered up.

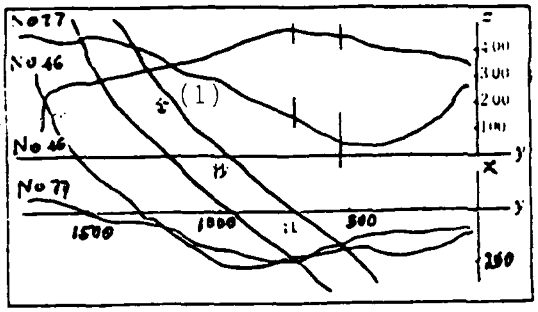

Fig. 4. Effects of Jingsha River valley
Key: (1) Jingsha River.

III. Determination Of Atmospheric Dispersion Parameters

1. Discussion Of Computation Methods

The Lekkāu wind velocity pulse data were obtained from the flight trajectory of a single balloon. Based on the Taylor theorem, the three-dimensional atmospheric dispersion parameters are computed from the following formulae:

$$\begin{aligned}\sigma_x^2&=(\overline{u'^2})_{\tau,T}T^2\\ \sigma_y^2&=(\overline{v'^2})_{\tau,T}T^2\\ \sigma_z^2&=(\overline{w'^2})_{\tau,T}T^2\end{aligned} \qquad (2)$$

where u', v' and w' are the wind velocity pulses, respectively. The subscript τ represents the sampling time, T is the release (or travel) time. Here $(\bar{u}'^2)_{\tau.T}$, $(\bar{v}'^2)_{\tau.T}$ and $(\bar{w}'^2)_{\tau.T}$ represent the square deviations of sliding average velocity, respectively; that is to calculate the sliding average of wind velocity data over τ with respect to T, then the square deviations are obtained, respectively.

When using a limited number of wind velocity pulse sliding averages to obtain the dispersion parameters, their calculated values have

a tendency to drop irregularly as the time interval reaches a certain value. As the interval continues to increase, a decrease even in the absolute values of the calculated values will result. Therefore, it has been pointed out by people[3] that the maximum travel time should only be selected as 10-20% of the sampling time. We believe that, from the energy spectrum angle, this suggestion is reasonable. There are cutting effects on the low and high frequencies of the energy spectrum by the sampling time with a limited length and average time with a fixed interval. We computed the effects of limited sampling time ($\tau \neq \infty$) and average time ($T \neq 0$) on square deviation and found that: only when $\tau / T \geqslant 5$ can the closeness of $\sigma^2_{\tau.T}$ and $\sigma^2_{\infty.0}$ be assured. Therefore, it is appropriate to select the maximum sliding average interval T as 10-20% of τ.

In order to find the relationship between the sliding time interval and sampling time corresponding to the above phenomenon, the mathematical simulation method was used to conduct further analysis. Assume there is a vector $\vec{V}$ with unit length and it changes direction with respect to t. It changes randomly within a 360° range in space. If the y direction component of this vector at any time in an unit time interval is selected as the simulated y direction wind velocity pulse, then its standard deviation can be obtained by using the sliding average method. If the vector moves an unit distance in the x direction within an unit time, and when the samples are selected large enough, then it can be proved that:

$$\sigma_y = \left(\frac{x}{2}\right)^{0.5} = \left(\frac{t}{2}\right)^{0.5} \tag{3}$$

Twenty groups of the above number were generated randomly by computer with each group consisting of 50 and 80 random numbers. The standard deviation σ_y of different sliding time was obtained by using the sliding average. The calculated results show the following conclusion: (1) the calculated standard deviations of either 50 or 80 numbers are smaller than those calculated from formula (3). The larger the sliding time interval, the greater the decrease; (2) the relative velocities, which decrease as the time interval increases, of two numbers are in fair agreement. As they reach 10%, 20% and 30% of each individual length, the average values decrease by 4.0%, 5.1%; 14.2%, 13.7% and 24.5%, 25.0% respectively; (3) when sliding to 30% (for 50 numbers) and 40% (for 80 numbers) of the total length, the absolute values of the average values start to drop; (4) the standard deviation for each group is obtained successively and it is found that there is greater difference between each group. When reaching 20% of the total length, the maximum values are about 3 times larger than the minimum values. Figure 5 shows these effects.

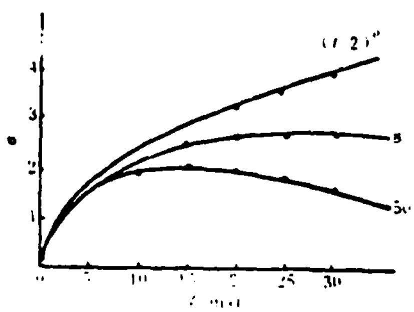

Fig. 5. Effect limiting number on sliding average

To use what method in computing the average values of σ under different atmospheric conditions is also an important question. We tried six average methods and compared the results, and the method with the best results was selected; i.e., first regrouped and converted

the data to obtain the coefficient A and index b in the index form of dispersion parameter, then computed the standard deviation of each group according to its index form, and lastly took the average value and converted it to obtain new A and b values.

2. Results

The atmospheric dispersion parameters were computed under five categories: stable (W), nuetral (W), neutral (E), unstable (E) and breeze which were divided according to atmospheric conditions, wind direction and wind velocity. The categorization of atmospheric conditions is mainly based on data from on-site low altitude temperature probings and determined by the following standards: i.e., $\left[\frac{\Delta T}{\Delta z}\right]_{100m}^{600m} < -0.5℃/100m$ is unstable; $-0.5℃/100m \leqslant \left[\frac{\Delta T}{\Delta z}\right]_{100m}^{600m} \leqslant 0.4℃/100m$ is stable. Neutral (W) includes a weak stable category and neutral (E) includes a weak unstable category. The calculated results of dispersion parameters for each category are shown in Table 1. It can be seen from Table 1 that: (1) under breeze, σ_x and σ_y are closer (value and trend of change), and they are both 3 times larger than σ_z; (2) under breeze, both σ_x and σ_y are much larger (3-5 times) than those under unstable, neutral and stable categories. σ_z is within the same magnitude as that under unstable category; (3) σ_x, σ_y and σ_z under the unstable category are larger than those under the neutral and stable categories. For the unstable category itself, σ_y and σ_z are a little larger than σ_x, and σ_y and σ_z are about the same magnitude; (4) σ_y and σ_z of the stable category are larger than those under the neutral category, σ_z is about the same magnitude as those

under the neutral category; (5) for the neutral category itself, $\sigma_y > \sigma_x > \sigma_z$. For the stable category, $\sigma_y > \sigma_x$ and σ_z, and σ_x and σ_z are about the same magnitude. These trends are in fair agreement with the actual conditions in the Dukou area. The breeze at Dukou usually occurs during the changing period of the mountain and valley breeze. At such time, the wind direction changes erratically and the balloon trajectories appear to curve horizontally. This is the primary reason that results in large breeze dispersion parameters. Except that the dispersion parameters under unstable category show a trend of equal characters in all directions, this trend is not obvious for those under other categories. This situation is reasonable for the Dukou area where the mountain is high, the valley is deep and the wind velocity at high altitude is small. σ_y and σ_z of the stable category are larger than those under the neutral category unexpectedly. It was discovered after inspecting the data of each group under stable category that: the releasing altitudes of the balloons in these groups were mostly located in the successively declining layer or the isothermal layer of the mountainous multi-layer temperature inversion structure, i.e., they were still flying in the unstable or neutral layer where there was string temperature inversion layer in the upper portion and either no temperature inversion layer or a thin temperature inversion layer in the lower portion. Thus, the temperature inversion layer only limited the balloon's ascent, yet did not exert very much influence on the balloon's descent. Since the influence was not uniform, the balloon was actually flying most of the time in the neutral or unstable category causing the dispersion parameters to be still quite large.

Table 1. Dispersion parameters under various conditions ($\sigma = Ax^{b}$)

(1) 层结(风向)		σ_x					σ_y				
		A	b	500m	1km	2km	A	b	500m	1km	2km
(2) 稳定(W)		1.4566	0.6275	71.28	110.77	173.53	0.5649	0.8835	136.19	252.11	468.74
(3) 中性	(W)	0.9842	0.7114	81.3	133.7	221.2	0.3864	0.8715	86.7	158.9	292.0
	(E)	0.9412	0.7129	78.7	129.3	213.1	0.6308	0.8499	124.0	223.8	403.6
(4) 不稳定(E)		1.2861	0.7057	103.2	168.4	274.6	0.7535	0.8464	145.0	260.8	468.9
(5) 微风(中性)		1.4056	0.8920	357.6	665.4	1242.4	1.2968	0.8942	334.4	623.2	1165.9

(1) 层结(风向)		σ_z				
		A	b	500m	1km	2km
(2) 稳定(W)		0.6267	0.7459	64.46	108.26	182.18
(3) 中性	(W)	0.5497	0.6730	35.6	57.2	92.6
	(E)	0.6636	0.7614	62.6	106.4	181.3
(4) 不稳定(E)		0.8608	0.8229	142.8	252.3	447.4
(5) 微风(中性)		1.0047	0.7826	128.5	222.8	389.8

Key: (1) Condition (Wind direction); (2) Stable (W); (3) Neutral; (4) Unstable; (5) Breeze (neutral).

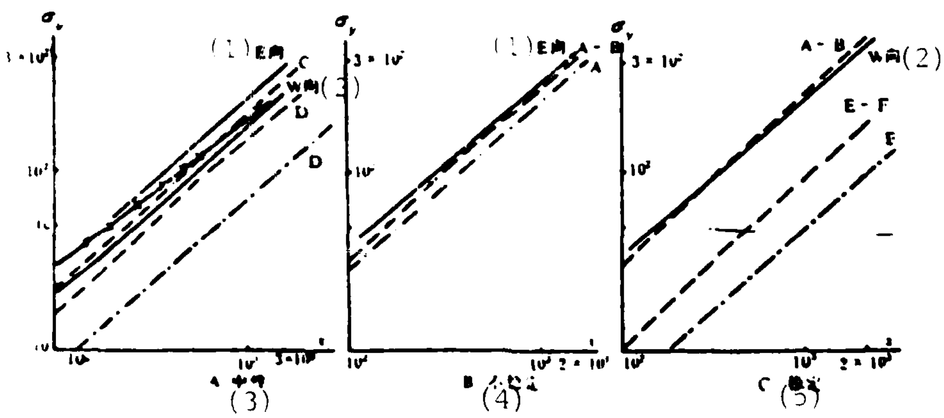

Fig. 6. Comparison of σ_y curves

——— On-site probing at Dukou ---- Briggs -·-·- P-G

—x— Wind tunnel simulation at Dukou —Δ— Photographed at Dukou

Key: (1) E direction; (2) W direction; (3) A. neutral; (4) B. unstable; (5) C. stable.

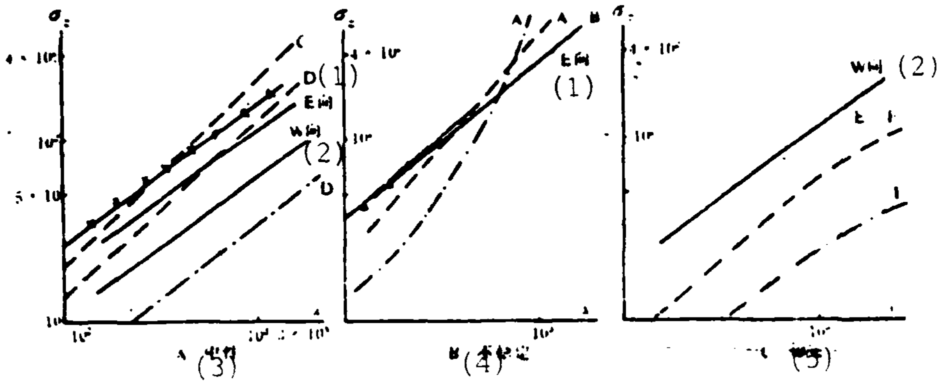

Fig. 7. Comparison of σ_z curves (Same legends as Fig. 6)
Key: (1) E direction; (2) W direction; (3) A. Neutral; (4) B. Unstable; (5) C. Stable.

IV. Conclusions

The experiments have shown that, as long as detailed and in-depth studies are conducted on the probing method of the balanced balloon and processing, computation and analysis of its data, it can be utilized in complex mountainous terrain to obtain excellent effects. It can be observed from this experiment that there were many features in the local flow field of a mountainous area and the atmospheric dispersion followed the special rule. The results of on-site probing have provided reliable parameters for the study and application of the air quality model at Dukou.

Using the sliding average of a limited number of data to calculate atmospheric dispersion parameters will cuase decreases in calculated values. The drop starts to become obvious when the sliding time interval reaches 10-20% of the total sampling time. When it reaches 30-40%,

the absolute values of dispersion parameter start to drop. This requires that we obtain as long a sampling time as possible. Under conditions where the actual sampling time is long enough, it is better to take the sliding average time interval to be 10% of the total sampling time, but not to exceed 20% at the most; otherwise there will be larger errors between the calculated dispersion parameter values and the observed values. When conducting balanced balloon observations in a mountainous area, the observation might be terminated prematurely due to the obstruction by terrain or land objects causing the data collected to be insufficient. Therefore, the rate of selective elimination of the data group tends to be higher. This is a problem which demands serious attention and improvement.

The study in this paper was part of the Dukou environmental quality overall evaluation research subject. During the course of this study, full support and assistance were received from the coordination group. The Bureau of Meteorology of Dukou City not only provided us with part of the high quality meteorological data, but also supported and participated in part of the field work. We hereby express our special thanks to all of them.

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